Population Fragmentation of Spotted Frogs

in the Owyhee Mountains

Final Report

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Introduction

This report is based on a three-year study conducted from 1997-1999 on population fragmentation in the Great Basin population, Owyhee subpopulation of Columbia spotted frogs. It includes a synopsis of the 1999 field data and looks at the three years collectively to reveal short-term trends and population demographics.

Previous reports (Engle and Munger 1998, 1999) described the importance of understanding the movement behavior of this candidate species in determining population structure. Subsequently, by assessing population structure, we can assess the short-term viability of the population. This study focused on the observations of movements of individuals within the subpopulation using an intensive mark-recapture method with passive integrated transponder (PIT) tags.

Our goal for the first year (1997) was to PIT-tag as many frogs as possible so that over the next two years we could detect movements and assess population structure. The second year (1998) we concentrated on the Rock Creek drainage, again PIT-tagging as many individuals as possible and closely monitoring areas of greatest spotted frog density. Last year (1999), we again surveyed the Rock Creek drainage, but in addition we surveyed the adjacent watersheds to search for individuals previously PIT-tagged in the Rock Creek drainage. Movements of individuals to and from a hibernaculum were also monitored in 1999 and 2000.

Study Site

The Rock Creek drainage (centrally located in Owyhee County, just north of Mud Flat Road) was the focus area for the 1999 field season, including those streams immediately encompassing the Rock Creek area (Figure 1). Surveys were conducted on Federal, State, and private land, excluding approximately three miles of Rock Creek and three miles of Pole Creek on private land where access was denied.

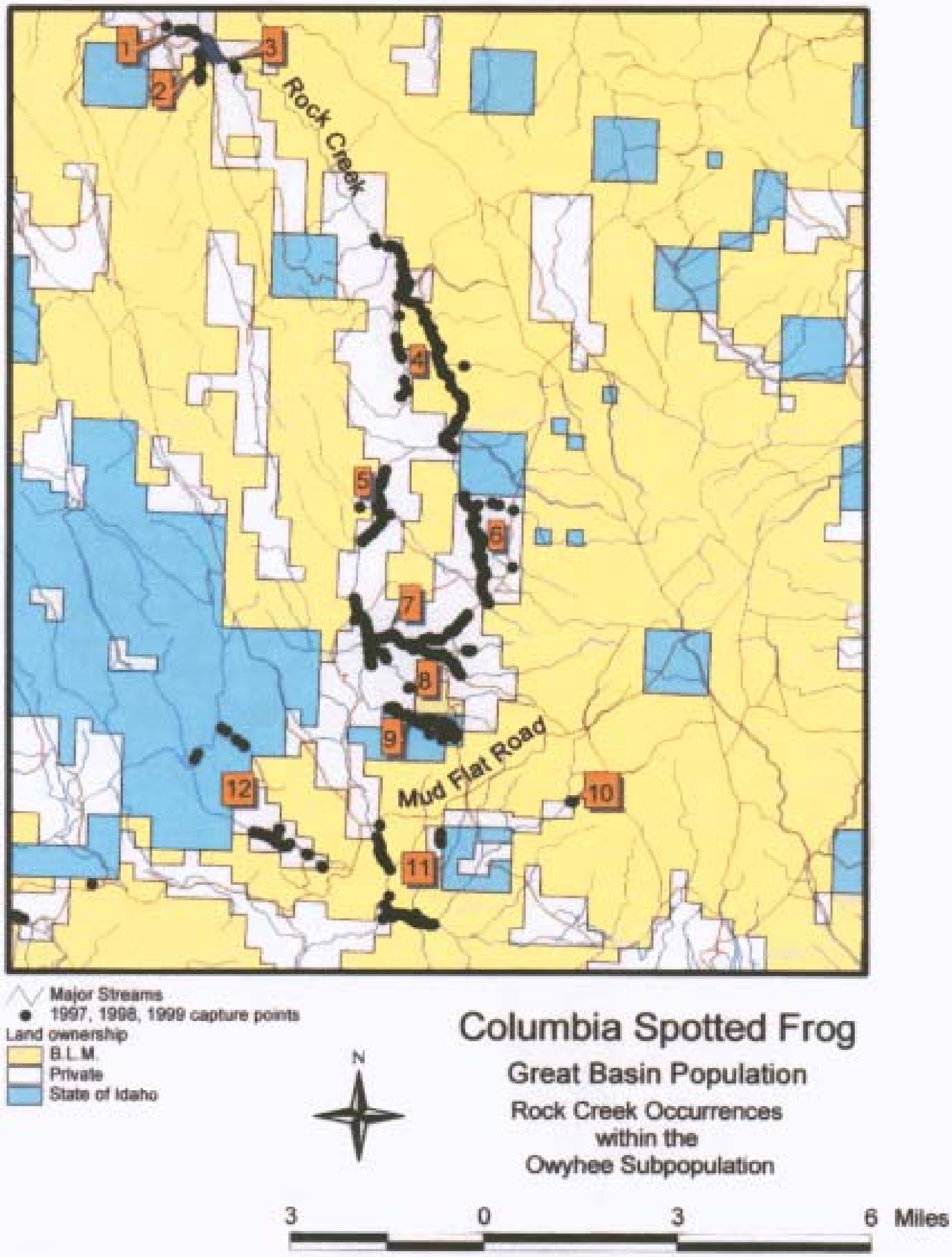

Figure 1. Rock Creek study area within the Owyhee subpopulation. Numbers represent the twelve element occurrences surveyed.

(refer to Table 1 for names of each occurrence).

Materials and Methods

In 1999, field surveys began in mid-April with the documentation of the emergence from hibernation and the onset of breeding in the Sam Noble Springs area. Overwintering individuals were identified as they were captured in pitfall buckets adjacent to a drift fence encircling a hibernacula. Egg mass deposition sites were recorded and individual breeders were identified.

In mid-May as accessibility increased, surveys began throughout the Rock Creek drainage and adjacent streams. Stream courses and ponds were visually surveyed and spotted frogs were captured by dip-netting. The date and time of each capture was recorded along with the individual's sex, weight, and snout vent length (SVL). A GPS reading of each capture location was recorded and all frogs greater than 40mm SVL were PIT-tagged.

Surveys continued full-time through July. In August through November, select occurrences were monitored for recruitment and late season movement. "Occurrence" refers to the disjunct sites at which spotted frogs have been observed within the Owyhee subpopulation.

Results & Discussion

A total of 1140 observations were recorded in 1999 including captured and uncaptured individuals. To date, there are 1849 individuals PIT-tagged, and of those, 497 have been recaptured at least once (172 frogs were PIT-tagged in areas not revisited, reducing the overall recapture rate). Additionally, over the three years, 79 subadults were too small to PIT-tag and 287 frogs avoided capture.

The Rock Creek study area is divided into twelve element occurrences, as defined by the Natural Heritage Program (Appendix I). Table 1 summarizes survey totals for 1999 in these twelve occurrences.

Table 1. Surve totals for the 1999 field season.

LOCATION *(Refer to numbers on Figure 1)*	**ADULTS**	**SUBADULTS**	**UNCAPTURED**	**#DAYS**
1. Triangle Meadow	5	5	0	1
2. Louisa Creek	13	3	0	1
3. SE Triangle Reservoir	2	0	0	1
4. Rock Creek (Island)	89	29	13	11
5. Rock Creek (Collett)	31	40	3	3
6. Collett Ranch	67	9	2	7
7. Long Tom Creek	73	15	7	6
8. Isolated Spring Pond	0	0	0	1
9. Sam Noble Springs	205	31	4	37*
10. Pole Creek Spring	5	0	0	1
11. Pole Creek Drainage	84	52	5	4
12. Toy Valley	94	3	8	4
TOTALS	**668**	**187**	**42**	**77**

*includes short visits to monitor drift fence buckets only.

Recapture data showed that only 5 females and 3 subadults traveled over 1000m (Figure 2). The greatest distance between capture points was 6.5 km, downstream by a subadult along Rock Creek from May 1998 to June 1999. The other two subadults were both captured initially on May 31, 1998 and traveled 1437 and 1431 m from the eastern end of the Sam Noble Springs area to the western end of that occurrence (also downstream). One subadult covered the distance in two weeks, the other in six weeks. By far, most individuals were recaptured close to their original capture point; 188 were recaptured within 10 m, and 441 within 500 m (Figure 2). Of the 497 recaptured individuals, 29 are not included in Figure 2 because of GPS errors.

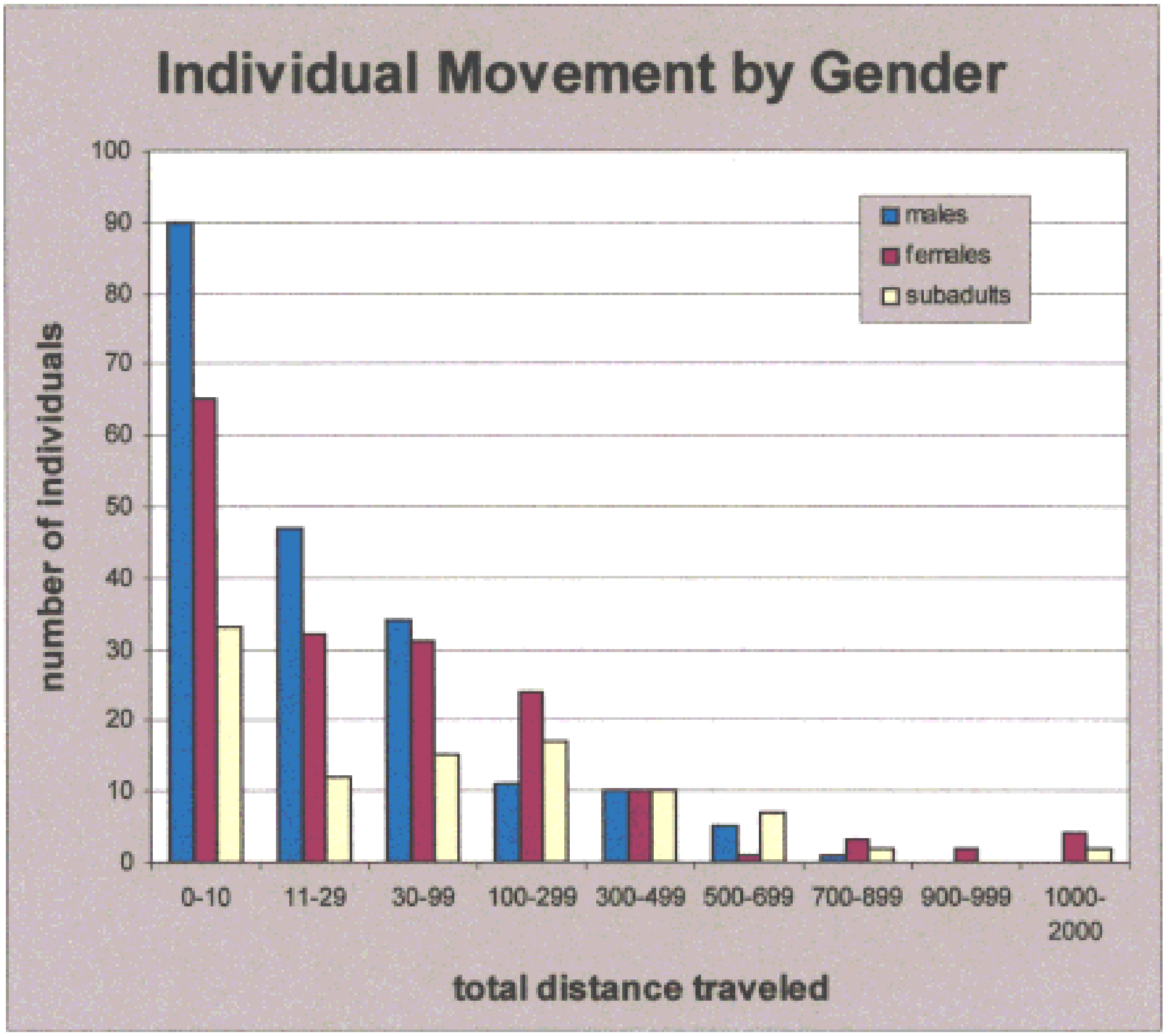

Figure 2. Total distance in meters between capture points.

Of 198 males, 86% were recaptured within 99 m of their original capture point. Of 172 females, 74% traveled less than 99 m, and 61% of the 98 subadults were recaptured within 99 m (Table 2). Possibly, a higher percentage of subadults actually attempt this dispersal-type movement, but their small size made them very susceptible to predators and desiccation, especially over a long

Table 2. Numbers of individuals, by gender, that traveled each distance.

Distance (m)	0-10	11-29	30-99	100-299	300-499	500-699	700-899	900-999	1000-2000
males	90	47	34	11	10	5	1	0	0
females	65	32	31	24	10	1	3	2	4
subadults	33	12	15	17	10	7	2	0	2

distance in grazed areas. The male that traveled the greatest distance (762 m) was captured three times: July 8, 1997, June 30, 1998, and May 19, 1999, moving from one end of a meadow to the other, but was always found in standing water. It is likely that he overwintered in a reservoir protected by willows in a small valley and moved out each spring to forage in the adjacent wet meadow. Movements by other individuals were widespread in meadows, but always limited to wet areas and then to spring ponds as the meadows dried. Barriers to movement included dry upland habitat and ephemeral stretches over 0.25 mi. No individuals were found to move outside of the riparian corridor. No individuals crossed watersheds at the heads of those watersheds, even over distances as short as 0.25 mi. (Figure 3).

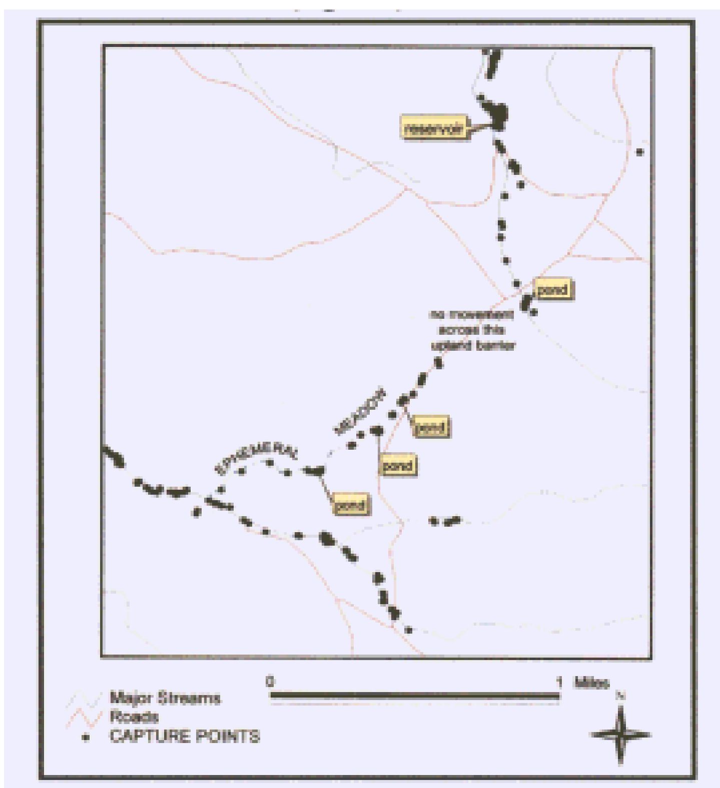

Figure 3. Spotted frogs were not captured in adjacent drainages. The most promising location would have been this 0.25 mi distance between two occurrences.

The following movement information was collected at the Sam Noble Springs occurrence, at the headwaters of Rock Creek. "SN" = Sam Noble Springs, and "1", "1a", etc. refer to improved spring ponds (Figure 4).

Figure 4. Aerial view of the Sam Noble Springs area. Yellow numbers are improved spring ponds.

Of 11 frogs captured both in the fall and subsequently in the early spring, 9 were males, 1 was female and 1 was subadult. The female had moved from SN2 and hibernated at SN1a. None of the females caught at SN1a in the fall of 1998 were breeders in 1999. I would have expected the breeding females of the next season to be the last up in the fall, adding as much metabolic reserves as possible before hibernation, but this was not the case.

Ten females were up at SN1a in April & early May 1999...6 were breeders, 4 juveniles.
The 6 females that bred at SN1a have interesting "backgrounds":

-one was a subadult at SN in 1997
-one was a big adult at SN2 on 4 August 1997
-one was only captured this one time
-one was at SN3 on 12 July 1998
-one was an adult near SN5 on 16 July 1997
-one has always been at SN1a (first capture 20 May 98).

However, in 2000, recapture information on the breeding females at SN1a revealed that only one female had successfully ventured farther than SN2 (and she showed up at the breeding site after egg mass deposition was completed). Recapture information gives us the following on the twelve females at the oviposition site at SN1a in April, 2000:

-one was at SN1a in 1997 & 1998, SN1 in 1999, SN1a for hibernation (not a breeder).
-one was at SN2 in 1998, but overwintered at SN1a (probably not a breeder).
-one was at SN4 in July 1997 and September 1999 (arrived late-not a breeder).
-one was captured at SN1a since 1998, and was not a breeder.
-one was captured at SN11 since 1999, and was not a breeder.
-one was at SN1 in June 1998, SN1a in May of 1999, and bred at 1a in 2000.
-one has been captured exclusively at 1a since 1998 and bred there in 2000.
-one has been captured at SN1 since 1998; hibernated at SN1a, but bred at SN1.
-two have been captured exclusively at 1a, and bred there in 1999 and 2000.
-one was a new capture, and bred at SN1a in April 2000.
-one was captured at SN1, but overwintered at SN1a in 1999 and 2000 (bred at SN1)

Other movement data of interest showed 9 frogs (8 males and 1 female) moved from SN2 to SN1a to hibernate. None moved the other direction.

Of 117 subadults in the 1998 dispersal, 2 were at SN1a in 1999, I went 6.5 km downstream and the other 115 were not recaptured. No large dispersal was observed in 1999.

The recapture rate (across a winter) for subadults varied between Sam Noble and the Collett Ranch:

Sam Noble Springs: 0.096 (23/240)

Collett Ranch: 0.21 (16/77)

(This is a huge difference in recaptures, especially considering that the Sam Noble Springs area was surveyed much more intensively.) It appears that heavy fall grazing in the Sam Noble Springs allotment is causing increased mortality on subadults and females due to the lack of vegetative cover and reduced water corridor during the period in which these individuals are migrating. Although it was not uncommon to observe minor deformities in toes and webbing, one subadult was discovered to be missing all bone below the knee on the left leg. It appeared as if his foot was attached directly at the knee, with no tibia/fibula. This individual resided at the exclosed SN1a pond and was captured in 1999 and 2000.

Table 3. shows the demographics of the individuals that were present at the breeding site during April of 2000. The numbers will increase as individuals emerge from hibernation, but it is important to note that based on recapture information alone, some individuals live for at least five years. Skeletochronological analysis in 1998 revealed a 9-year old female. As PIT-tag efforts continue, a clearer picture will develop as to the movement over the years of these longer-lived frogs.

Table 3. Number of captures per gender and age class at the breeding site in April 2000.

Year first captured	females	males	subadults
1997	2	5	
1998	6	16	
1999	3	8	1
2000	1	2	5

Could the Sam Noble Springs area be serving as a "source" of frogs that can disperse to other areas? Possibly. However, Sam Noble Springs occurs at the head of a drainage and no movement has been detected away from any drainage at a head. Although movement has been observed in both directions (upstream and downstream) throughout the meadow area, it appears there is a net loss downstream, especially of females and subadults. Assuming the ratio of males to females is 50:50 at metamorphosis, it is likely that females are being lost in a greater proportion from this occurrence because they are more wide-ranging than males and are unable to return to natal ponds and hibernacula due to heavy fall grazing. Over time, this has caused a consistently skewed gender ratio. Of particular import is the temporary loss of a suitable movement corridor between the foraging areas and hibernacula in the fall, and then between hibernacula and breeding sites in the early spring. The only "stopover" between good habitat (substantial willows and springs) is one small patch of willows centrally located in the meadow. In the fall, the rancher salts and supplements (ingredient list includes selenium) his livestock at these willows and in the riparian corridor, resulting in further compaction of the soils, loss of vegetative cover, increased desiccation and pollution. The willows have been damaged and the water table has dropped. The water that is left in the late fall when frogs are returning is isolated by up to 0.25 mi, highly concentrated with urine and manure, and completely denuded of all vegetation. Then the frogs still have to make it from the isolated patch of willows across another dry stretch with no vegetation to the hibernacula at the spring ponds.

It is probable that frogs are being lost from east to west across this occurrence and additionally downstream (on unsurveyed private land). 14% of the males, 26% of the females and 39% of the subadults go over l00 m. If they are heading from the springs at the east end to forage toward the west, and then are unable to return to hibernate because of a barrier that exists during the fall migration, then the gender ratio will indeed remain skewed and the population will in time begin to decline.

Intensive monitoring during April 2000 identified a further complicating factor: natal pond fidelity. This discovery casts some doubt on the ability of the Sam Noble Springs frogs to serve as a source for recolonization of habitat downstream. If a portion of the frogs exhibit natal pond fidelity while some still disperse, then recolonization is possible. Additional monitoring should help us to determine the extent to which natal pond fidelity and dispersal occur.

Breeding activities

Intensive observance of breeding activity began on April 12, 2000. Using the exclosure at SN1a as a marker for movement, we identified those individuals breeding and determined their movement patterns across four years. Males were observed to vocalize both at the water's surface and underwater during the day. Vocalizations began one week prior to breeding and abruptly ended with the cessation of egg laying. Egg laying lasted approximately one week (slight variation from site to site), qualifying this as an explosive breeder. Short breeding season fosters scramble competition among males for females, minimizing the opportunity for males to obtain multiple mates. Temperature data indicated that breeding began when the water temperature suddenly increased at the oviposition site, not at the hibernaculum. The hibernaculum temperature was a constant 6°C from February until late April. However, the temperature at the oviposition site was at 0°C from December 1999 to April 3. On April 4 it took a steady turn upward, and by April 10 was ranging from 5°C at night to 11°C during the day (Figure 5). Oviposition sites were communal, along shallow banks in still ponds, oxbows, or eddies with southern aspects (with few exceptions).

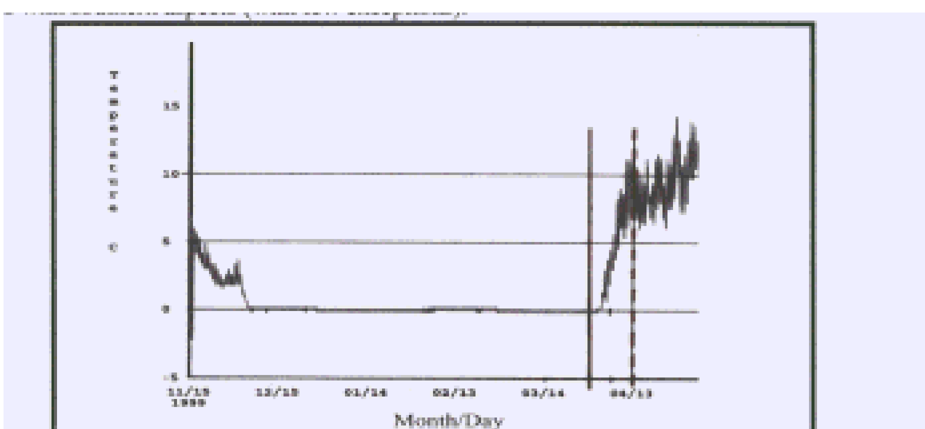

Figure 5. Temperature record for the oviposition site at Sam Noble pond #1a. Solid red line represents April 1, dotted red line represents the beginning of amplexus, and oviposition was from April 16-21.

While *Rana pretiosa* showed a more balanced ratio of males to females at an undisturbed breeding site in Oregon, this was not the case at the Sam Noble Springs occurrence. In both cases, the males emerged from hibernation first and moved toward the breeding site. In Oregon, however, this first wave of hundreds of males was followed by several hundreds of pairs in amplexus, and then by a relatively small number of single females. The movement was clearly migratory from the overwintering site (a small lake) to a nearby marsh. Trapping revealed females were "programmed" to reach a particular site and relocation did not alter their dedication to return there to lay their eggs (Jay Bowerman, pers. com.). While the movement in the Owyhees also appears migratory , the paired and female components were virtually absent. There were 32 males and 12 females at the SN1a breeding site. Two females departed while still gravid and three were not considered to be gravid. Because 12 egg masses were observed there, it is likely that some females are "halving" their egg masses. This will be confirmed or refuted (along with the multiple mating by males) by genetic analyses (in progress) of the egg masses being conducted by Dr. Michael Blouin at Oregon State University.

Natal pond fidelity

It appears that the females exhibit natal pond fidelity. One female entered into amplexus with a male at the hiberculum at SN1a and was subsequently captured (still in amplexus with the same male) a week later in a drift fence bucket (leaving 1a). The next day anew egg mass was observed at SN1 (possibly from this pair). Another gravid female was observed in the SN1a hibernacula (dug up on April 7). She was captured in a drift fence bucket (leaving 1a), still gravid on April 22. She has hibernated at SN1a for the past two years, but moved to SN1 to breed (Table 4).

Table 4. Movement for an adult female, indicating natal pond fidelity.

Date	mass	SVL	location	probable activity
13-July-98	18.4	58	Sam Noble pond #1	foraging
20-Apr-99	23.0	64	Sam Noble pond #1a (bucket 1, exited)	going to breed at #1
21-May-99	18.6	63	Sam Noble pond #1 seep	foraging (weight loss)
4-Aug-99	30.5	68	Sam Noble pond #1a	toward hibernacula
7-Sept-99	28.2	68	Sam Noble pond #1a	hibernacula
7-Apr-00	30.0	68	Sam Noble pond #1a (dug out of hibern.)	hibernacula
22-Apr-00	29	67	Sam Noble pond #la (bucket 6, exited)	going to breed at #1

It is not known why these females hibernated at #1a when #1 also appears suitable for overwintering (except possibly that #1a was protected from disturbance). No individuals were found to hibernate at SN#1 and then try to enter #1a for breeding. Since the females have been observed to migrate in amplexus, natal pond fidelity in males is negligible. Once in amplexus, the male does not release until oviposition has occurred.

The female's preference to deposit her eggs in her natal pond presents another factor potentially reducing the number of females in the Sam Noble Springs occurrence. Not only do the females have to travel in the fall amongst adverse conditions, but in the spring, when all vegetation is still denuded and temperatures are extreme, they need to make another trip to their natal pond (if their natal pond is not a hibernacula).

Most egg masses were observed at ponds that had willows and springs nearby (Figure 6).

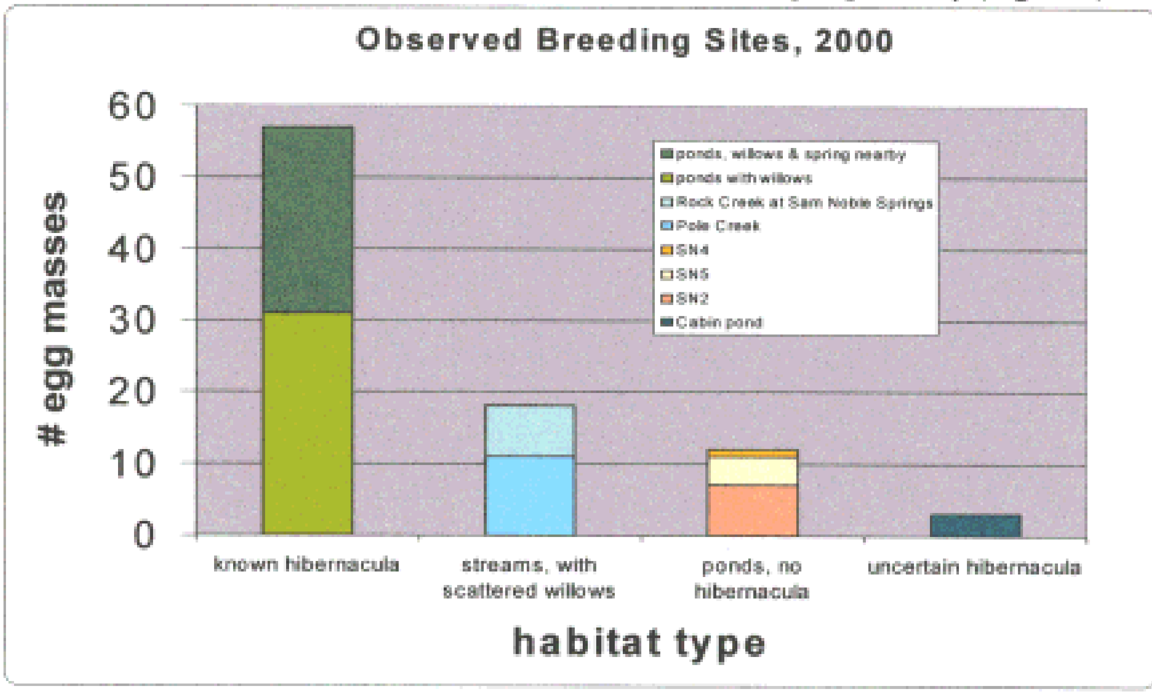

Figure 6. Numbers of egg masses observed in various habitat types.

Although many areas were surveyed, only those where eggs were observed were recorded in Figure 6. A preference for quiet ponds with overwintering sites was observed, although spotted frogs also utilized eddies of streams (second), and ponds with no hibernacula (third). Additionally, egg masses were deposited at an earlier date at sites that contained a hibernaculum (Figure 7). It took individuals at least one week to move to breeding sites away from hibernacula.

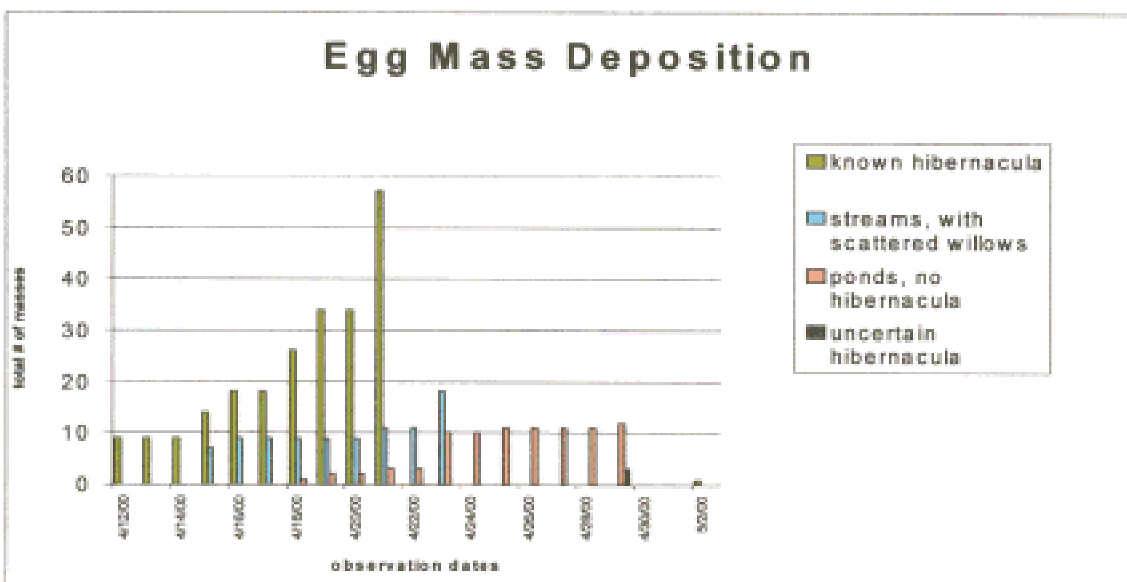

Figure 7. Dates of egg mass deposition, showing the variation between habitat types.

The following insect larvae were observed on one egg mass at the SN4 breeding site:
Hemiptera, Corixidae
Diptera, Chironomidae
Copepoda, Cyclopoida
Trichoptera, Lepidostomatidae
Ephemeroptera, *Baetis*
Amphipoda, *Hyalella azteca*
Oligochaeta (worm)
Many of these were consuming the algae present within the egg mass, not preying directly upon the eggs. Eggs were observed to develop in three to four weeks at the breeding sites, but in warm, controlled conditions in the lab, a random sample developed in one week. Many masses became desiccated by receding water levels during that period of time. Two of twelve egg masses at SN1a did not develop. One egg mass at SN1 had only 9 of 190 eggs hatch and only four of those became viable tadpoles (the other five were deformed). In a random sample of eggs from the remaining egg masses, 68% developed into tadpoles and 32% were not viable (unfertilized or died).

Summer activity
Frogs were observed to move away from the overwintering and breeding sites in late spring. Those frogs not involved in breeding generally emerged in mid-May. Foraging activities were observed in meadows and movement occurred most frequently at night. Monitoring of the buckets at the drift fence revealed exclusive nocturnal movement to and from the pond in June of 1999. While the number of captures varied greatly due to weather and individual sites, a peak in visible activity seemed to appear in late May and June. A decline in capture numbers as the season progressed could be due to an increase in vegetative cover. At the Sunriver *Rana pretiosa* site in Oregon, hundreds of frogs were observed leaving a marsh in which less than 10 individuals were observed during the summer (Jay Bowerman, pers. com.). Clearly they were there, just extremely difficult to observe in the thick vegetation of mid-summer. In clear water conditions along Rock Creek, frogs were observed inactive on the bottom substrate. Tattersall and Boutilier (1997) discussed the movement of frogs throughout the water column during the winter to optimize temperature and oxygen conditions. Likewise, during the summer frogs need to remain in aerobic conditions during periods of inactivity, especially since the water temperature is higher. It is unlikely that the frogs aestivate for long periods buried in the mud unless there is a seep providing cool, oxygenated water. Individuals that were recaptured at identical locations probably reduced their activity level, but surfaced occasionally for oxygen, to thermoregulate, and to forage.

Fall movement toward overwintering sites
Recapture data in the Owyhees shows that some individuals return to their overwintering sites as early as August, while some wait until the last possible moment (freezing nights and snow) in November. The fall *Rana pretiosa* migration in Oregon is more clearly defined temporally, but the site lends itself to a distinct migration route between a lake and a marsh. Migration patterns between summer foraging and overwintering sites have been discovered at Sam Noble Springs as well as at the Collett Ranch (Figure 8).

Because of this clear migration pattern, it is important to recognize that studies that manipulate small patches of habitat (i.e., small grazed vs. ungrazed exclosures) may incorrectly pinpoint a "preference" for the treatments. The motivation to go to or through an area may be programmed in the frog as part of his or her migration route, and his/her presence there may have nothing to do with the treatment. If studies are needed to determine the effects of different environmental conditions on spotted frogs, migrational routes would need to be determined up front and natal pond fidelity should be considered when interpreting results.

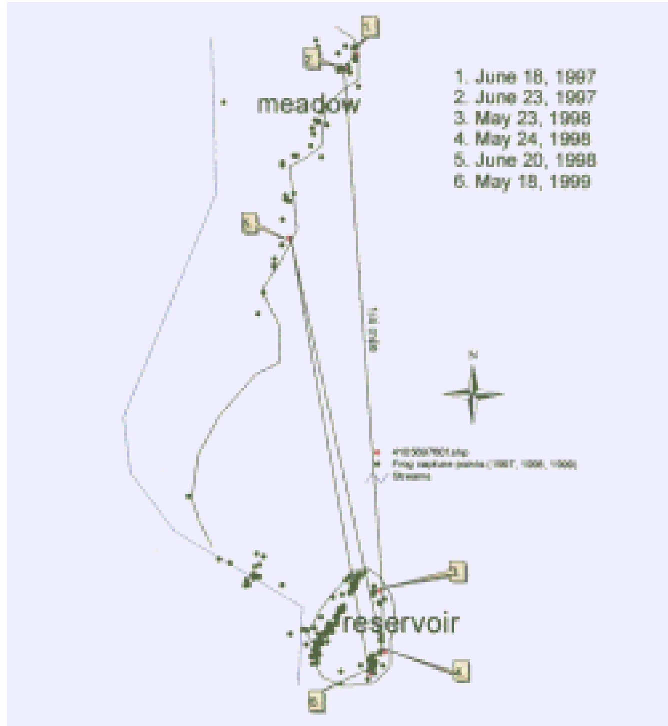

Figure 8. Migrational movement over a three-year period of one male between summer foraging and winter hibernation sites. (Black line follows capture locations chronologically, although movement probably occurred along the wet corridor to the west.)

Conclusions

During the short-term (1997-1999), the Owyhee subpopulation numbers steadily decreased. In some occurrences (Stoneman Creek, for example), numbers plummeted, while in others (Rock Creek), the decline was less dramatic, but steady. Climatic conditions combined with fragmentation and disturbance of suitable habitat patches and movement corridors by livestock were factors negatively influencing population numbers. Heavy grazing during fall migration was linked to the unusually skewed gender ratio and subadult loss at the Sam Noble Springs occurrence. Heavy grazing results in severely hummocked surfaced soils, often breaking the dense sod, exposing mineral soil and thus increasing erosion potential and weed invasion (Manning and Padgett 1995). Hansen et al (1995) adds, "the wet nature of these soils makes them highly susceptible to damage by livestock and heavy machinery. These disturbances often lead to soil compaction, streambank sloughing, damage to vegetation, and premature drying of the soil surface." It appears that the grazing activity at Sam Noble Springs does indeed increase the premature drying of the soil surface, and the water level does not rebound until the following spring. Not only is all vegetation removed, increasing evaporation, but each cow drinks 10-15 gallons per day (at least 500 cows x 10 gallons = 5000 gallons of water removed daily during the driest part of the year by drinking alone). At Sam Noble Springs, frogs were not observed at ponds that became turbid and concentrated with manure and urine, but were active at pond la, which had an exclosure fence.

Forty-nine separate occurrences were documented in Owyhee and Twin Falls Counties, and eleven of those were proposed to be included in a long-term monitoring plan in development by the U.S. Fish and Wildlife Service. The best way to determine the long-term trajectory of the Owyhee Mountain subpopulation is to conduct this long-term monitoring program at a number of occurrences, and document population estimates (decline and recovery) through another drought cycle and under controlled grazing regimes.

Recommendations for Land Use Managers

Based on the current knowledge of Columbia spotted frog life histories and their population distribution in the Owyhees, the following management strategies are recommended to foster successful frog persistence over the long term:

- Terminate late fall grazing in riparian corridors used by spotted frogs to return to hibernacula.

- Employ a flexible and frog-sensitive method of determining grazing intensity. (Grazing intensity should be determined based on the needs of the frogs.) This recommendation would provide for modification of grazing intensity in drought years.

- Terminate periodic extensive grazing to remove all vegetation.

- Move salt blocks and forage supplements at least 0.25 mi from the nearest riparian area.

- Reintroduce willows along riparian corridors and in improved spring ponds. Terminate the complete burning of willows in riparian areas.

- Fence riparian areas of known spotted frog source populations, to include all overwintering, breeding and foraging sites.

- Monitor select occurrences for long-term persistence and population fluctuations as prescribed in the USFWS Long-term monitoring plan for at least the next ten years.

- Reestablish habitats previously flooded by beaver by repairing abandoned dams.

- If reintroductions are attempted, egg masses should be transplanted (not adults).

Literature Cited

Engle, J.C., and J.C. Munger. 1998. Population structure of spotted frogs in the Owyhee Mountains. Idaho Bureau of Land Management, Boise, ID. Technical Bulletin 98-20. 10pp.

________, and ________. 1999. Population fragmentation of spotted frogs in the Owyhee Mountains. Interim report to the Bureau of Land Management (unpublished). Boise State University, Boise, ID.

Hansen, P., R. Pfister, K. Boggs, B. Cook, J,. Joy, and D. Hinckley. 1995. Classification and management of Montana's riparian and wetland sites. Montana Forest and Conservation Experiment Station Miscellaneous Publication No. 54. 478pp.

Idaho Conservation Data Center. 2001. Idaho species of special concern: element state ranking reviews. Idaho Department of Fish and Game, Boise, ID. 104pp.

Manning, M., and W. Padgett. 1995. Riparian community type classification for Humboldt and Toiyabe National Forests, Nevada and Eastern California. USDA Forest Service, Intermountain Region R4-Ecol-95-01.

Tattersall, G., and R. Boutilier. 1997. Balancing hypoxia and hypothermia in cold-submerged frogs. Journal Experimental Biology 200:1031-1038.

APPENDIX I
Element Occurrence Specifications

EO SEPARATION: EOs are separated by either (1) a major barrier to dispersal such as a busy interstate highway, highway with impassable obstructions, major river (greater than 50 m wide), or habitat in which site-specific data indicate the frogs virtually never occur (e.g., some semiarid shrubland habitats); (2) a distance of at least 1 km for general unsuitable but occasionally traversable habitat; (3) a distance of at least 5 km of suitable habitat for occurrences in different drainages in montane habitat; (4) a distance of at least 10 km of suitable habitat for occurrences within a drainage in montane habitat (for both 2 and 3, a lesser distance can be used if site-specific data indicate that individuals in adjacent populations are not likely to come in contact with each other). All separation distances are measured from the outer edge of the occurrence (see mapping guidance) (Idaho Conservation Data Center 2001).